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LA-UR-87-2664

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TITLE THE USE OF INDUSTRIAL ENERGY IN SEVEN OECD COUNTRIES

LA-UR--87-2664

DE87 014733

AUTHOR(S) Ronald J. Sutherland

SUBMITTED TO To be included in the Proceedings Volume of the IAEE Meeting held in Calgary, Canada, July 6-8, 1987

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Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

THE USE OF INDUSTRIAL ENERGY IN SEVEN OECD COUNTRIES

by

Ronald J. Sutherland

Energy Systems Analysis Group
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

ABSTRACT

The objective of this study was to analyze the industrial demand for energy in seven Organization for Economic Cooperation and Development (OECD) countries with particular emphasis on fuel substitution between oil, natural gas, coal, and electricity. Changing fuel demand also results from economic growth, changes in industrial structure, and changes in the energy intensity of industrial output. A historical analysis of these factors and fuel substitution is undertaken for industry as an aggregate, and for 12 specific industries. The major results of the historical analysis are: (1) fuel use changes are a result of fuel switching, changing energy intensity, changing industrial structure, and economic growth; (2) fuel substitutability depends upon fuel use. The three fossil fuels are substitutes in the industrial heat market, but there are numerous special industrial processes where a particular fuel is required; (3) large substitutions have occurred between fuels; (4) fuel substitutions have been very different across countries, both in the type of substitutions that have occurred and the factors accounting for the substitutions; and (5) in most countries, major changes in fuel use can be explained by two or three industries, suggesting that future analyses be industry specific.

I. INTRODUCTION

The objective of this study is to analyze the industrial demand for energy in seven Organization for Economic Cooperation and Development (OECD) countries: Canada, France, Germany, Italy, Japan, the United Kingdom (UK), and the United States (US). A particular focus is on fuel substitution between oil, natural gas, coal and electricity. Changing fuel demand results from fuel switching, economic growth, changes in industrial structure, and changes in energy intensity of industrial output. A quantitative historical analysis of these factors and fuel substitution is undertaken for industry as a whole, and for twelve specific industries.

The aggregate analysis of the 1960 to 1973 period indicates that economic growth is the main variable accounting for changes in fuel use, with fuel switching being next most important. During the 1973 to 1982 period, fuel switching was the most important variable explaining changes in fuel use. The fossil fuels are substitutes for each other but not for electricity. However, there is no clear trend of one fossil fuel being a close substitute for another fossil fuel. Substitutions involving electricity for fossil fuels generally involve structural changes in industry, and not merely fuel switching.

The industry specific analysis, conducted for the 1973 to 1982 period, indicates that fuel substitution is the most important variable explaining the trend in fuel use. In some countries a change in fuel use is broad based across industries. In most countries, a major change in the use of a fuel could be explained by at most three industries. The chemicals and petrochemicals industry is important because in 1983 it accounted for about 39 percent of the total industrial demand for energy making it the largest energy user. The iron and steel industry has been important historically because it is the second largest energy user and because its energy use has decreased substantially in the last decade. A third industry is often important in explaining historical trends in energy use but the industry varies between countries. In the United States and Canada, the paper and pulp industry is important. An implication of this analysis is that the effects of a significant rise in the price of a fuel can be explained by understanding the use of fuel in a few select industries.

II. AGGREGATE ANALYSIS

Before presenting quantitative evidence on the importance of the factors that explain the amount of fuel used; we present a graphic overview of the historical trends in industrial energy to conserve space we depict in graph some one country-France. As seen in Fig. 1, industrial energy use relative to GNP has declined significantly since 1973. A partial explanation of this trend in industrial energy use is that the industrial sector has become less energy intensive since 1973 (second panel). An additional explanation is that output in the industrial sector declined relative to total output, as shown by

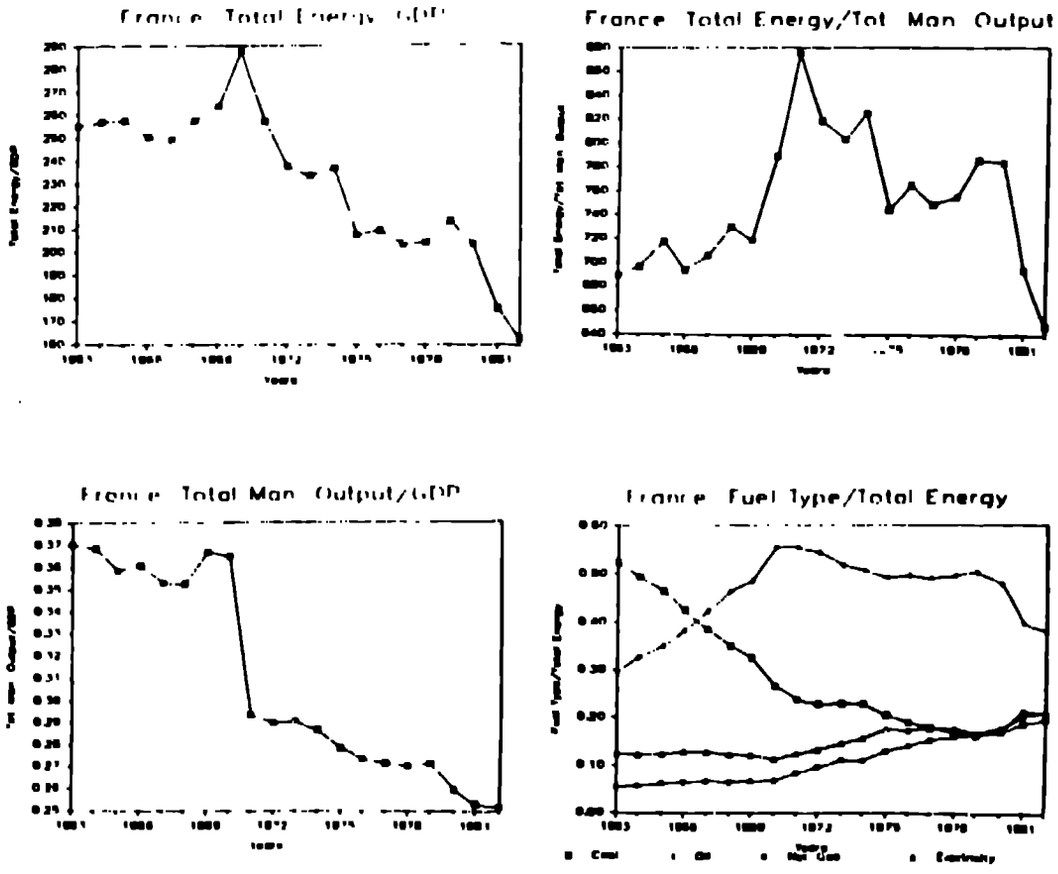

Fig. 1. Energy, output and fuel share trends in France, 1963-1982.

the third panel. These latter two trends are important for understanding the historical demand for industrial energy. They imply that industrial energy demand has grown relatively slowly since 1973 because the relative size of the industrial sector has diminished and because the industrial sector has used less energy relative to output. Similar trends in industrial energy use characterize the other OECD countries being considered, except Canada, where the manufacturing sector has become more energy intensive.

Panel 4 in Fig. 1 depicts the fuel shares of the French industrial sector over the 1963 to 1982 period. There are wide variations in fuel shares over time and this result applies to each of the seven countries. Several countries shifted out of coal before the early 1970's and out of oil thereafter, with other fossil fuels being the apparent substitutes. The wide variations in fuel shares, both temporally and between these seven countries, suggest that significant fuel changes may occur in the future. Particularly, a continued decrease in oil dependence may be possible. If natural gas were available in Europe at a competitive price and with secure supplies, a significant increase in the share of this fuel could occur. The stable increase in the share of electricity in these countries implies that electricity is not a close and direct substitute with the fossil fuels; rather substitutions occur indirectly and over a long period of time and involve a change in the structure of industry.

The mechanism by which fuel substitutions occur has four components: fuel switching, changes in energy intensity, changes in product mix, and changes in economic output (GNP or GDP). Fuel switching is the substitution of one fuel for another where total output, energy, and product mix are unchanged. Changes in product mix in the aggregate refer to the changes in the ratio of total value-added in the industrial sector to the total GNP. At this level of aggregation, product mix is simply the industrial share of total output and is referred to as industrial structure. In the industry specific analysis, industrial structure is defined as total output of a specific industry divided by the sum of total output of all 12 industries. The ratio of total energy used to total industrial output measures energy intensity and changes in the ratio may reflect conservation or changes in technology. The fourth source of change in fuel use is economic growth. Estimates for these four components are constructed for each of the seven countries and for each of four fuels; coal, natural gas, petroleum, and electricity.

Following Werbos (1983), we estimate the mechanism by which changes in the demand for fuels occur by beginning with Eqn. 1:

$$\text{Fuel} = \left(\frac{\text{Fuel}}{\text{Total Energy}}\right) \times \left(\frac{\text{Total Energy}}{\text{Output}}\right) \times \left(\frac{\text{Output}}{\text{GNP}}\right) \times \text{GNP} \qquad (1)$$

which is an identity because each term except fuel can be cancelled from the right hand side. Although Eqn. 1 is an identity, it is useful in allocating the changes in fuel use over time into the four components discussed above. First, changes in the fuel-energy ratio reflect fuel substitution or fuel switching. Changes in the energy-output ratio show changes in energy intensity and refer to the amount of energy required to produce one unit of output. Changes in this ratio may be due to changes in technology or to energy conservation. The industrial output-GNP ratio accounts for structural changes in the whole economy on an aggregate basis. Finally, in the absence of changes in these ratios, fuel consumption will change at the same rate as GNP.

Equation 1 is estimated for each country and for each of the years 1960, 1973, and 1982. The ratios cannot be compared across countries because GNP and industrial output are measured in different currency units and consequently, apparent energy intensity differs across countries. If changes in the ratios over subperiods were computed as percentage rates of change, the currency unit problem would be solved. However, the sum of the percentage changes on the right hand side would not equal the total percentage change in fuel use. Each of these problems is solved by estimating Eqn. 1 using logarithms.

All energy data were obtained from Energy Balances of the OECD Countries; which contains data by country, fuel type, industry and for the 1960 through 1982 period. Industrial output data was obtained from The Growth of World Industry, published by the United Nations.

Equation (1) is estimated for each of the seven OECD countries in first differences of logs and the results by country are in Table I. Estimates are reported for both subperiods and for each of the four fuels. The last three terms on the right hand side of Equation 1 are independent of fuel type and therefore the changes in these variables are the same for each fuel.

Table I contains the estimates of fuel use changes in each of the seven countries and the importance of the variables that account for changes in fuel demand. For example, in Canada the most significant fuel use changes during the 1960 to 1973 period are the decline in coal use and the increase in the use of oil and natural gas. Changes in the ratios of energy to industrial output and industrial output to GNP had offsetting effects and neither change is very large. Fuel switching and economic growth are therefore the dominant variables explaining fuel use in Canada during this period. The large increase in GNP, measured by a change in the log of GNP of 70.6, implies an increase in the demand for each fuel used in industry. However, there occurs a significant substitution of other fuels for coal, as measured by the change in the log of fuel share of coal of -85.24, and hence an overall decrease in coal use. The increases in oil and natural gas usage are due to fuel substitution for coal complemented by overall economic growth.

TABLE I

FACTORS EXPLAINING CHANGES IN FUEL CONSUMPTION BY TYPE OF FUEL

	Canada		France		Germany		Italy		Japan		United Kingdom	United States	
	1960-73	1973-82	1960-73	1973-82	1960-73	1973-82	1960-73	1973-82	1960-73	1973-82	1973-82	1973-82	1973-82
Fuel Type													
Coal	-14 3	68 1	-38 2	-28 9	-39 2	-36 2	29 1	16 7	48 1	-1 4	-77 6	10 0	-25 7
Oil	104 7	-35 7	100.8	-44 7	162 5	-53 6	142 2	-64 7	235 2	51 7	-73 8	82.7	-6 9
Natural Gas	139 4	29 8	114.2	50 4	261 3	6 4	79 9	5 1	102 9	30 7	24 5	45.1	-38 7
Electricity	51 03	20 6	59 6	23 2	78 1	5 2	86 4	13 6	137 7	7 4	-14 1	44 3	3 5
Fuel Switching													
Coal	-85 2	52.3	-83 2	-14 6	-93 6	-8 1	-75 4	43 3	87 4	20 8	-34 2	-38 4	-3 1
Oil	33 7	-51.5	55 8	-30 4	188.2	-25 6	37.7	-38 0	99 7	-29 5	-30 3	42 3	15 7
Natural Gas	68 5	13 9	69 2	64 6	207 0	34 4	-24 6	31 8	-32 6	52 9	67 9	4 5	-16 1
Electricity	-19 9	4 8	14 6	37 4	23 8	33 2	-18 1	40.3	2 2	29 6	29 5	3.9	26 1
Total Energy													
Industrial Output	8 8	16 6	15 3	-21 6	3 5	-36.3	28.2	-30.1	-5.1	-39.2	-22.9	-6 5	-12 5
Industrial Output													
GNP	-8 4	-19 5	-24.2	-14 3	-5 3	-6 7	9 2	-15.4	12.4	-16 5	-27.5	-6 2	-12 5
GNP	78 6	18 8	53.9	21 6	56 2	15 0	67.1	18.9	128 2	33 5	7 0	53 2	16.6

Rather than consider the countries individually, the results are examined for common trends. First, industrial value-added relative to total output declined in each of the seven countries for the post-oil embargo period. The energy intensiveness of the industrial sector declined in six of the seven countries considered after 1973 (not Canada). These trends imply that a decrease in the overall industrial demand for energy occurred after 1973, and is independent of fuel substitutions. Economic growth was positive, although historically low, in the seven countries following 1973. The effects of economic expansion tended to partially offset the negative effects on fuel use of a decreasing energy intensiveness and a declining industrial share. The second trend is the decrease in oil consumption during the post embargo years in all countries except the US. The change in the logarithms of oil consumption is large and negative for the six countries, indicating a substantial reduction in oil consumption. The decrease in oil consumption is explained by fuel substitution complemented by decreasing energy intensity and the industrial share of output.

The third trend is in changing fuel shares. The share of oil consumed decreased in each country with the US being the exception. In the US, the share of oil increased because of the significant reduction in the use of coal due to environmental regulation and natural gas because of supply constraints. There is a general trend for the share of electricity to increase in each country during each subperiod. The exceptions are that electricity's share neither rose in Canada between 1960 and 1973, nor in Italy between 1973 and 1982. As seen in Table I, changes in electricity consumption are often accounted for by factors other than fuel switching. The last common trend is that the share of coal used in industry declined in each country during the pre-oil embargo period. In the following period, three countries, Canada, Italy, and Japan, switched back into coal, but the remaining four countries, US, UK, West Germany, and France, did not.

Similarities also appear in the overall growth of each fuel and in each of the countries during the first subperiod. Economic growth surpassed the importance of fuel switching as evident by the large positive numbers for GNP. This relationship reversed during the 1973-1982 period with decreasing industrial output and decreasing energy intensity. Table I shows that changes in these ratios are generally negative and are often of equal size to changes in GNP.

An important observation from Table I is that fuel substitutions are strikingly different across the seven countries. The main substitute for coal during the 1960-1973 period was natural gas in Canada, France, and Germany, but it was oil in the US, Japan, and Italy. After 1973, each country switched out of oil but tended to switch into different fuels. Coal showed the largest share increase in Canada and Italy, whereas natural gas showed the largest share increase in the UK, Japan, and France, while West Germany substituted both gas and electricity for oil. Italy substituted oil for coal during the pre-embargo period and

subsequently switched back to coal. Italy is the only country that reciprocally substituted fuel types. Substitutions have usually been between the fossil fuels, and generally not between a fossil fuel and electricity.

III. INDUSTRY SPECIFIC ANALYSIS

We now consider the importance of specific industries in explaining aggregate changes in fuel use. We are particularly interested in whether such changes can be accounted for by one or two industries, or, whether they are broad based across industries. Because this analysis is industry specific, industrial structure is now defined as the ratio of value-added in each industry to the total value-added in all industries. Eqn. 1 is applied to each industrial sector instead of to the total industrial sector.

Data limitations in the energy balance statistics require that the analysis be slightly changed. The period of analysis is from 1973 to 1982 because industry specific data are not available before 1973. Second, the data lists the 13 "specific" industries along with a residual industry, termed "nonspecific." The nonspecific entry may include up to one-third of the total fuel used but it balances total fuel used by industry with the amount of fuel reported by each of the 13 specific industries. The nonspecified entry is not included in this analysis. Third, the distinction between the Chemical and Petrochemical industries is not the same between countries nor has it been consistent for individual countries. These two industries are therefore combined leaving a total of 12 industries.

The estimates of Eqn. 1 identify the industries that explain fuel use changes and the process by which these substitutions occurred. The energy balance data are also used to identify the major fuel changes and the industries that account for these changes. For brevity the discussion of results is limited to Canada.

As depicted in Table I the major fuel change in Canada after 1973 is a shift out of oil and into coal. For instance, the change in the log of coal is 68.1 and the change in the log of oil is -35.7. Logarithms, however, do not measure the absolute amount of fuel used so the raw data (energy balance data) must be re-examined. Since the energy balance data are so voluminous, only a few numbers are reported here. A review of the coal and oil data for total industrial fuel use confirms a dramatic increase in coal consumption and corresponding decrease in oil consumption for total industry. Solid fuel use for the total industrial sector doubled from 60,587 MTOE (1973) to 128,636 MTOE (1982) while oil decreased from 161,214 MTOE to 104,908 MTOE.

A review of the energy balance data for coal used by industry type, reveals that no industry shows a large increase in coal use. The growth appears in the nonspecified industries, which precludes further analysis of the change. Oil use declined in

Canadian industry and the data indicates that it is broadly based across industries. The total decline in Canadian industrial oil use from 1973-1982 was approximately -155,000 MTOE, with the largest decline being experienced in the paper products industry (-16,000 MTOE), followed by nonmetal products (-7,000 MTOE), iron and steel and chemical and petrochemical products (-6,000 MTOE each). The quantitative importance of these various industry changes is measured using Eqn. 2 and the results are presented in Table II. The change in industrial oil use is depicted as a combination of fuel switching, energy intensity, product mix, and economic growth.

Although the aggregate (Table I) and industry specific (Table II) analyses each point to fuel switching as the major factor explaining the decline in Canadian industrial oil use after 1973, the industry specific analysis adds some detail. First, the paper products industry not only accounts for the largest decrease in oil use, but fuel switching and decreasing energy intensiveness are equally important (Table II). In the nonmetal products industry, fuel switching explains most of the decrease in oil use. Decreasing energy intensiveness and a declining share of value-added also explain the decrease in oil use. Table I indicates that total industrial output decreased relative to GNP. Table II shows that iron and steel and nonmetal products are the major industries where total output declined.

IV. IMPLICATIONS

This quantitative description of fuel use trends in seven OECD countries suggests a qualitative interpretation in terms of the underlying lines of causality. Fuel use changes can be explained in part, but only in part, by the conventional economic variables of price and income effects. Fuel switching is due in large measure to changes in relative fuel prices, with higher oil prices and the backing out of oil after 1973 being one example. The decreasing energy intensity of industry after 1973 is also consistent with the increasing energy prices, which were led by petroleum. Rapid economic growth during the 1960 to 1973 subperiod, along with favorable energy prices, contributed to the increase in energy use overall.

However, some of the fuel use changes that occured cannot be accounted for by a simple price and income analysis. The post-1973 decline in energy use in several of these countries was led by declines in the iron and steel industry. These declines can be explained not just by fuel prices but by factor endowments and factor prices of the seven OECD countries relative to their international competitors. The significant shifts in industrial structure, as measured by changes in the share of value added by twelve industrial sectors, are important in accounting for some of the major fuel use trends.

This analysis of historical fuel data yields important implications that may be useful in anticipating future industrial energy demand. Over each time period we observed

TABLE II

CHANGES IN FUEL CONSUMPTION BY TYPE OF FUEL AND INDUSTRIAL SECTOR, AND FACTORS INFLUENCING THESE CHANGES, 1973-1982

CANADA

	Iron & Steel	Chemical & Petrochemical	Nonferrous Metals	Nonmetal Products	Transport Equipment	Machinery (Except Electrical)	Mining	Food Products	Paper Products	Wood Products	Construction	Textiles
Fuel Type												
Coal	-18.98	204.92	-76.01	- 22.72	-73.83	--[a]	--	--	2.63	--	--	--
Oil	-42.70	-15.66	-58.12	-116.40	-67.20	-40.07	--	-36.45	-35.05	69.06	--	--
Natural Gas	3.70	86.25	-19.83	- 13.65	13.27	35.52	--	34.18	-11.99	--	--	--
Electricity	20.83	20.97	14.56	3.25	8.77	37.47	--	59.38	10.44	54.28	--	10.14
Fuel Switching												
Coal	- 5.20	183.22	-67.14	16.96	-63.66	--	- 8.53	--	16.29	--	--	--
Oil	-32.92	-37.35	-89.25	- 76.71	-57.03	-69.29	-29.34	-53.81	-21.40	89.59	--	--
Natural Gas	13.48	28.56	-10.97	26.03	23.88	6.30	34.42	17.22	1.67	--	--	--
Electricity	30.61	- 0.72	23.42	42.98	18.98	8.25	5.98	42.42	28.10	38.81	--	-128.65
Energy/Ind. Output	13.76	- 1.55	- 8.30	- 20.16	5.19	22.55	--	7.62	-21.97	63.66	--	154.75
Ind. Output/Total Ind. Output[b]	-22.76	28.02	0.21	- 19.75	-14.59	7.88	--	10.11	9.09	-43.42	--	- 15.18

NOTE: All numbers are the change in the (natural) logarithms from the beginning to the end of the period.

[a]The dash (--) indicates that the change in the logarithm could not be calculated, usually because of a zero data point.

[b]Total Industrial Output is -0.77.

very substantial shifts in fuel shares and in total fuel use. For instance, industrial oil consumption decreased in Italy from 292,679 MTOE in 1973 to 154,169 MTOE in 1982. This case is one of several where these countries made major changes in their fuel consumption over a multi-year period. Major fuel shifts may also be feasible in the future, which is important because the industrial sector of the seven countries is still relatively dependent on petroleum.

In the larger study upon which this paper is based, we noted that fuel substitutability depends on fuel use. Fuel is used in the industrial heat market to raise steam. The share of industrial energy used in this way varies from 44 percent in Japan to 69 percent in the United States. Energy is also used in the various industrial processes to manufacture goods. Finally, we examined special industrial processes where a particular fuel is uniquely well-suited to a manufacturing process. In these cases, fuels are not substitutes, except by changing industrial processes, or by changes in the share of the particular industry. In several industrial processes, fuels are often not close substitutes. The three fossil fuels are substitutes in the industrial heat market, although changes in the capital stock are generally required.

Fuel substitutions have been very different across countries and between the two subperiods. There is not a consistent pattern of one fuel substituting for another, except that electricity does not appear to be a close substitute for any other fuel. However, electricity is not used in the industrial heat market. The three fossil fuels are, in general, substitutes over a several year period. The absence of clear patterns in fuel substitutions occurs because the process by which industrial energy demand responds to changing prices is highly variable across countries, across industries, and over time. In addition to fuel switching, changing energy intensity, and structural change in industry, we find that some fuel changes were broad based across industries, but others were concentrated in one or two industries. In many countries it is feasible to understand aggregate fuel substitution possibilities by understanding the industrial processes, and hence fuel uses, of one or two important industries.

The above results offer implications about the feasibility of modeling industrial energy demand with an econometric model. The changes in industrial energy demand analyzed here take place over a several year period because they involve changes in the capital stock. Econometric procedures to estimate distributed lags, such as the Koyck lag, are not reliable. Hall (1986) estimated a Koyck-type lag and failed to obtain a statistically significant dynamic response. The long run response of industrial energy demand to changing energy prices cannot readily be estimated with conventional econometric methods. Long run elasticities are estimated using cross-section data reflecting several countries. This type of analysis requires that each country is in equilibrium and has the same demand curve. Adjusting to equilibrium requires changes in the capital

stock and includes changes in industrial structure. These responses require several years and have been quite different between the seven countries considered. Cross-section (inter-country) energy price-quantity data probably reflect different demand relationships in disequilibrium.

Econometric equations are sometimes estimated separately for each country, but are usually constrained to represent the entire industrial sector. An implicit assumption in aggregating across industries is that the marginal response to changing fuel prices is constant in each industry. A major change in the price of a fuel would impact about equally the various industries within a given country. However, the use of fuel, e.g., industrial heat, varies with the industry, and hence so does fuel substitutability. In some countries a change in fuel use was broadly based across industries; but in several countries a major fuel use change could be explained by one or two leading industries. In these countries, an aggregate industrial energy demand function would be a biased representation of energy demand. An important implication of the industry specific analysis is that econometric estimates of industrial energy demand should focus on specific industries, and should not aggregate across industries without appropriate statistical justification.

ACKNOWLEDGEMENT

This study is based upon a larger effort, "The Industrial Demand For Energy in Seven OECD Countries," by Ronald J. Sutherland, Robert W. Schultz, and C. Ellen Smart, Los Alamos National Laboratory, Los Alamos, New Mexico, forthcoming.

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